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Effect of glycerol, peanut oil and soybean lecithin contents on the properties of biodegradable film of improved cassava starches from Côte d'Ivoire

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***Abstract*—** *Edible films have been successfully used in the food packaging industry for several decades. Today natural polysaccharides, including cassava starch,are increasingly being used in the production of such biodegradable edible films and food packaging. In Côte d'Ivoire, there are improved cassava varieties whose starches have not yet been tested in the production of biodegradable films. In thisstudy, the optical and mechanical properties and the water solubility of starch-based composite films of four improved cassava varieties withadded glycerol, peanut oil and soy lecithin were determined. Starchwas obtained by cold water extraction from native cassava from the varieties Bocou 1, Bocou 2, Yavo and TMS. Films preparation was made bycasting methodwithcassava, glycerol (25-30 %), peanutoil (5-10 %) and soybean lecithin (0-5 %). Increasing the glycerol content, increased L*color valueand elongationat break and decreased a*, b*, colourdifference (ΔE^*_{ab}) and tensilestrength of the composite films. Also, increasing the oil content from 5 to 10%, increased the opacity, b*, ΔE^*_{ab}, water solubility, elongationat break but decreased L*, a* and tensilestrength. Similarly, increasing the soy lecithin content from 0 to 5%, increased the opacity, L*, b* and ΔE^*_{ab}, but decreased a*, of the starch-based composite films. The results suggest an ideal formulation of 4% starch/25% glycerol/5% oil/5% soy lecithinfor a film with optimum mechanical properties with low solubility.*

***Keywords*— Biodegradable film, Cassava starch, Emulsified film, Mechanical properties, Starch-based film.**

I. INTRODUCTION

Scientific literature now contains several studies aimed at improving the properties of materials already used or using new materials to produce packages having properties that may tend towards synthetics. Due to increasing pressure from society and legislation to reduce non-degradable synthetic packaging, research on the production of biodegradable alternatives prepared from natural biopolymers has been encouraged (Adjouman *et al*., 2017). Biodegradable films are flexible and thin matrices used for coating and packaging in a diversity of product groups and industries. Main applications include food packaging, fruit coatings, pharmaceuticals and cosmetics. Films are predominantly made of natural biopolymers, such as polysaccharides, proteins and other abundant natural elements (Bergo*et al*., 2010).

Starch is a polysaccharide composed of amylose, a linear polymer consisting of glucose with α (1–4) bonds, and amylopectin, a polymer with α (1–6) bonds. The amylose vs amylopectin ratio and, consequently, the form

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and functionality varybetween cultivars within and between species (Copeland *et al*., 2009). Cassava (*Manihot esculenta* Crantz) roots are among the most important sources of starch worldwide. According to the Food and Agricultural Organisation (FAO), the global cassava production in 2015 was estimated at 281.1 million tonnes with 54 % produced in Africa (FAO, 2016). In Côte d'Ivoire cassava is the second major food crop after yam, with an estimated 5.1 million tonnes produced in 2015 (FAO, 2016).Unlike other starches, cassava starch allows obtaining transparent and flexible films (Vicentini and Cereda, 1999). However, for the production of edible films and optimised application in food technology plasticizers, hydrophobic agents and emulsifiers have to be added to the film composition (Bergo*et al*., 2010). Adding vegetable oils to hydrophilic films, for instance,reduces the water vapor barrier properties of films based onproteins (Fabra*et al*., 2009) and those based on polysaccharides (Koelschand Labuza,1992). Those emulsion-based films with enhanced physico-chemical and mechanical properties generally arise from oil droplets with small diameter, a high degree of homogeneity and highly stable film-forming emulsions(Nilsuwan*et al*., 2016; Debeaufort*et al*., 1995). For good dispersion/homogenization of the oil in the film-forming matrix, emulsifiers are therefore commonly added. They are nonpolar substances which bind to both water and oil, thus improving emulsification and increasing the stability of the emulsion. Furthermore, soybean lecithin incorporated into protein-based emulsified films has previously shown effective in stabilizing the emulsion film (Prodpran*et al*., 2007).Lipid compounds are used to modulate the water barrier properties of films; however, in hydrophilic suspensions they adversely affect the mechanical and optical properties of the resulting films (Yang andPaulson, 2000). The most effective plasticizers are generally those whose structure resembles the structure of the polymer they plasticize.For starch-based films polyols such as sorbitol and glycerol are the commonly used plasticizers (Mali *et al*., 2005). With increasing glycerol concentration, the breaking strain has shown toimprove and the tensile strength to decrease (Alves*et al*., 2007).

In Côte d'Ivoire, there are improved cassava varieties whose starches have not yet been tested in the production of biodegradable films. The aim of this study is to determine the effect of plasticizer, lipid and emulsifier contents on the mechanical properties, solubility, opacity and color parameters of films based on starch from improved cassava varieties grown in Côte d'Ivoire.

II. MATERIALS AND METHODS

Cassava natives starches from four improved varieties Bocou 1, Bocou 2, Yavo and TMS, belonging to Centre National de RechercheAgronomique in Côte d'Ivoire were used in this study.Cassava plantswereharvested at maturity, 12 months after plantation. Glycerol (bidistilled, 99.5% purity) and soybean lecithin were purchased from VWR Prolabo Chemicals (Leuven, Belgium). The CORA brand peanut oil used in this study was purchased at a supermarket in Belgium.

2.1. Amylose content

The amylose content of the starch samples was determined by colorimetric reaction and subsequent measuring of the absorbance of the amylose-iodine blue complex formed (Morrison and Laignelet, 1983).

2.2. Starch pasteclarity

The paste clarity of the starches was determined as previously described by Craig et al. (1989). Approximately0.11 g of starch was weighed into quartz screw tubes. The mass was supplemented to 10 g with distilled water. The closed tube withthe well homogenized content wasleft inaboiling water bath at 100°C for 30 min with uniform stirring. The solution obtained was cooled and the paste clarity or percent transmittance (% T) was determinedusing a Shimadzu UV-2401-PC (Kyoto-Japan) spectrophotometer at 650 nm against a blanksample containing distilled water.

2.3. Film preparations and thickness measurements

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Film preparation and thickness measurements were determined in accordance with previously described protocol (Adjouman *et al.*, 2017). The emulsified films were prepared in two steps. First, 4 g of cassava starch (w/w, starch) was mixed with glycerol (1–1.2 g) and with twothirds of distilled water, the final mixture being heated from 30°C to 75°C for 20 min. Peanut oil (0.2–0.4 g), soybean lecithin (30–60 mg)and distilled water (a third of the total mixture) (Table 1) was also heated together for 20 min from 30°C to 75°C. Both solutions were heated with constant stirring at 750 rpm/min. Thereafter, the solution of peanut oil, soybean lecithin and distilled water was homogenised at 24,000 rpm for 2 min using an Ultra-Turrax T25 basic (IKA Werke, Staufen /Germany). The homogenised solution was subsequently mixed with the starch and glycerol and then heated from 75°C to 95°C at 750 rpm stirring for 25 min. A 20 g aliquot of the final solution was transferred and spread with even thickness on the surface of a Petri dish (9 cm diameter)and oven-dried in a ventilated oven model (Memmert UF-110, Schwabach, Germany) at 35°C for 24 h. The dried films were removed and stored in a desiccator at 25°C for 48 h, before testing. The thickness of all films was determined using a hand micrometer (NSK, Japan) at 10 random positions ofthe films.

2.4. Film water solubility

Film water solubility was determined as previously describe (Lópezet *al.*, 2008). From each film pieces of 2 x 3 cm were cut and stored in a desiccator,containingsilica gel beads, for 7 days. Pieces were weighed to the nearest 0.0001 g and placed into test beakers with 80 ml deionized water. The samples were leftunder constant stirring at 200 rpm for 1 h at room temperature. After 1 h, any remaining pieces of film were subsequently collected by filtration, dried again in an oven at 60°C to constant weight and the proportionof total soluble matter was calculated.

2.5. Film opacity

Film opacity was determined in accordance with previously described protocol(Lópezet *al.*, 2008). Film sampleswerecut into rectangles of1 x 3 cm and placed inside a spectrophotometer cell. The absorbance spectrum (400–700 nm) was recorded for each sample using aShimadzu (UV-2401-PC Kyoto/Japon) spectrophotometer. Film opacity was determined by an integration procedure and expressed as absorbance units per nanometers (AU. nm).

2.6. Film color

The film L*, a* and b* color values were determined using aMiniscan XE HunterLab colorimeter (Virginia, USA) againstthe standard plate (L* = 93.5; a* = -0.61 and b* = 0.12). Color was measured on 8 x 8 cm segment of film. The total color difference (ΔE^*_{ab}) wascalculated using the following equation 1:

$$\Delta E * ab = \sqrt{(L*)2 + (a*)2 + (b*)2} \quad (1)$$

Film specimens were pre-conditioned at 62% RH and 25°C for 72 h prior to taking color measurements.

2.7. Mechanical properties

Mechanical properties were studied using a TA.TX2 Stable Micro Systems Texture Analyzer. ASTM D882-02(2002),standard test method for tensile properties of thin plastic sheetingwith some modifications was used. The films werecutinto 25 mm wide and 80 mm long strips, using a scalpel and mountedbetween the grips (A/TG) of the texture analyser. The ends of the stripsweremountedbetweencardboard grips. Strengthresistance and deformationat break wererecorded in tensile mode, during extension at 10 mm min^{-1}, with an initial 50-mm distance between the grips, until the specimensbroke.

2.8. Statistical analysis

UsingStatistica 7.1 software (Statistica), multivariate analyses of variance (MANOVA) wasperformed, to compare the means of the variousproperties of the filmformulations (cassavavariety and glycerol, peanutoil and soy lecithin added). Duncan's multiple range test at the 5% threshold, allowedlocating the differences.

III. RESULTS AND DISCUSSION

3.1. Amylose content and paste clarity

Paste clarity and amylose content of cassava varieties used in this study are presented in Table 2. The highest value of amylose was obtained with the TMS variety, followed by the varieties Yavo, Bocou 2 and Bocou 1. In contrast, the clearest starch gel was obtained with the Bocou 1 variety, followed by Bocou 2, Yavo and TMS.Starches with low amylose content have high paste clarity. Amylose contents are known to influence clarity of starch pastes.High amylose content may result in more opaque starch pastes (Schmitzet *al.*, 2006).

3.2. Film water solubility

Glycerol, oil and lecithin added showed a significant difference in the water solubility of the starch films ($p < 0.05$). Increasing the concentration of glycerol from 25% to 30%, oil from 5% to 10% and lecithin from 0% to 5% resulted in increased water solubility of the composite films from all varieties (Table 3).

Increasing the glycerol content from 25% to 30% allowed an increase in the water solubility of the films of the starches of the four varieties of cassava. Such observations were made in previous studies on films based on bitter and soft cassava starch on the film-forming capacity of corn starch amended(Lopez *et al.*, 2008; Belibi, 2014). The demonstrated positive correlation

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between the solubility of the films and the plasticizer concentration may be dueto the low molecular weight of the glycerol which enables it to be easily inserted between the polymer chains (Cuq*et al.*, 1997) and to the hydrophilic nature of glycerol (Lopez *et al.*, 2008). Furthermore, the increase in the glycerol concentration in biodegradable films was found to induce a marked decrease in the crystallinity of the starch films (Belibi, 2014). The less crystallites are formed in the films the more readily they will swell in the water and disintegrate. Consequently, this will express in higher water solubility (Maizura*et al.*, 2007).

Increasing the oil content from 5% to 10% increased the water solubility of the starch films of allcassava varieties which is likely to be due to hight degree of solubility of the fatty acids contained in the peanut oil. An increase in fat content increases solubility in water as long as the concentration of fatty acids is lower than the saturation level for an expected volume of water (Fakhouri*et al.*, 2009). Previous work on gelatin films with lauric, palmitic and stearic acidsrevealed indeed a positive correlation between water solubility and fatty acid content (Fakhouri*et al.*, 2003). Another study revealed that solubility of soy protein films showed a significant increase with the addition of lauric acid (Rhim*et al.*, 2002) supported by similar findings in wheat gluten films with added fatty acids (Gontard *et al.*, 1994).

The increase in soy lecithin content from 0 to 5% led toan increase in the water solubility of the starch films of all cassava varieties. It was hoped that the inclusion of compounds having hydrophobic characteristics (i.e. soy lecithin) could reduce the water solubility of cassava starch films; however, thisbehavior was not observed in this study. A study of edible composite films based on wheat gluten and lipids suggested that the increase in solubility due to addition of compounds with hydrophobic characteristics is related to the breakdown of the intermolecular bonds in the protein network and to the formation of weak interactions with hydrophobic substances (Gontard *et al.*, 1994). The subsequent increase in the solubility of cassava-based films when the concentration of soy lecithin is being raisedis likely tobe related to the breakdown of the intermolecular bonds in the starch network.

3.3. Film opacity

The opacity values of the starch films of the different cassava varieties as a function of the different formulations are presented in Table 4. At a given concentration of glycerol addition of oil allowed an increase in the opacity of the films of cassava starches. Similarly, at a given concentration of glycerol and oil, addition of soy lecithin caused an increase in the opacity ofcassava starch films.Highest values were found with films from TMS starch, followed by Yavo, Bocou 2 and Bocou 1. Added oil and lecithin and oil-lecithin combination showed significant differences in the opacity of the starch films of all cassava varieties ($p < 0.05$).

The increase in oil content from 5 to 10% allowed an increase in the opacity of the films of the starches of all cassava varieties, which is in line with previousstudy (Perez-Mateos*et al.*, 2009). Similar results were found in a study on the physical and barrier properties of composite films of apple pectin and manioc starch incorporated with *LaurusNobilis* oil and oleic acid (Taqi*et al.*, 2014). The authorsattributed this behaviourto the physical properties of oils at room temperature, which generally depends on the oil concentration in the film.The opacity of the films would therefore be linked to the oil droplets dispersed throughout the starch network and to the original color of the oil used. Similar observationswere madepreviously on the whiteness of gelatin film colorin relation to the sunflower oil dispersed in the emulsion(Perez-Mateos*et al.*, 2009) and opacity increase as a function of the fatty acid level in a film within a study onthe effects of fatty acid addition tothe properties of corn starch and gelatin films (Fakhouri*et al.*, 2009).

Increase in lecithin content from 0 to 5% allowed an increase in opacity of films from starches of all cassavavarieties. We attribute this increase to original state of yellow soybean lecithin and a hydrophobic compound. Incorporation of the hydrophobic substances into the hydrocolloid polymer HPMC matrix caused a decrease in the luminance of the films which resulted in an increase in their opacity in previous work (Quezada-Gallo *et al.*, 2000). An oil-soy lecithin combination also allowed an increase in opacity of starch films of fourcassava varieties which seems to be accumulation of theirindividual effects. Opacity was more pronounced in TMS starch films than in starch films derived fromthe three other varieties used in this study and is related to the intrinsic characteristics of each starch variety specifically the starches paste clarity (Table 2).

3.4. Film color

The color parameters (Fig. 1)of the films were significantly influenced by the addition of glycerol, oil and lecithin ($p < 0.05$).Increasing the glycerol content, led to increased L* (Fig. 1a) and decreased a* (Fig. 1b), b* (Fig. 1c) and ΔE^*_{ab} (Fig. 1d), of starch films from four cassavavarieties. Conversely, increasing the oil content, resulted in a decrease in L* and a*, and an increase in b* and ΔE^*_{ab}, of the starch films formulatedusingcassavavarieties. Lecithin addition, resulted in an increased L*, b* and ΔE^*_{ab}, but decreased a*, of starch films of cassavavarieties. The increase in b*, resulted in an increase in ΔE^*_{ab} of the resulting films. The study on HPMC films plasticized with 15 and 30%

glycerol was showed a slight increase in L* luminance but not a decrease in a*, b* and ΔE^*_{ab} indexes(Al Mahdi, 2006). However, our results concerning effect of oil oncolor parameters are consistent with studies on emulsified films based on gelatine of fish shell and palm oil(Tongnuanchan*et al*., 2015) and on the stability of the emulsion and the properties of gelatin films affected by palm oil and emulsifiers (Nilsuwan et al. 2016). Previous studies in films with soy lecithin as emulsifier reported highest b* and ΔE^*_{ab} values compared with other emulsifiers(Nilsuwan *et al*., 2016). Therefore, the colors of peanut oil and soy lecithin directly determined the color of the cassava starch films in this study.

3.5. Mechanical properties

Table 5 shows values of tensile strength and elongation at break of composite films based on cassava starch. Increasing glycerol contentfrom 25% to 30% resulted in a decrease in tensile strength at break and an increase in the elongation at break of films fromcassava starches varieties. It has already been pointed out by several authors that increase in level of plasticizer such as glycerol in starch films leads to a decrease in tensile strength and an increase in elongation at break (Alves*et al*., 2007; Bertuzzi*et al*., 2012; Sanyang*et al*., 2015). It has been shown that glycerol reduces the rigidity of the starch network, leading to a less orderly film structure and increasing the capacity of the polymer chain movement (Sothornvit and Krochta, 2005). These properties render glycerol a suitable plasticizer able to reduce intramolecular forces between starch chains and to promote hydrogen bond formation between plasticizer and starch molecules. An increasein elongation of films may be related to the fact that plasticizers decrease intermolecular bonds between amylose, amylopectin and amylopectin amylose phases of the starch and substituting them by hydrogen bonds formed between starch molecules and plasticizer (Sanyang*et al*., 2015). Such perturbation and reconstruction of starch molecular chains reduces stiffness and promotes film flexibility by allowing greater mobility of the chain. Zavarez*et al*. (2012) have shown that elongation of the polymers depends on the mobility of their molecular chains.

Increasing oil content from 5% to 10% resulted in a decrease in tensile strength and an increase in elongation at break of starch films from all four cassava varieties. Similar results have been obtained on films based on cinnamon oil incorporated cassava starch (Souza et al. 2013) and a variety of other films with other polymers (Lopez *et al*., 2008; Al Mahdi, 2006). The addition of lipids or oil to protein-based or polysaccharide-based films such as starch can reduce intermolecular interactions between polymer chains. The result is a decrease in stiffness with a concomitant increase in the extensibility/elasticity of the film obtained (Lopez *et al*., 2008; Souza *et al*., 2013). The combination of glycerol and lecithin influencedtensile strength and elongation at break of films based on cassava starch ($p < 0.05$).

At 25% glycerol, addition of soybean lecithin resulted in an increase in tensile strength and an increase in elongation at break for all varieties; however, at 30% the addition resulted in decrease intensile strength andincreases an elongation at break of the starch-based films. Thisbehavior observed at 30% glycerol when the soy lecithin is added could be due an apparent synergistic effect between glycerol and emulsifiers (Rodriguez *et al*., 2006). This interaction means that the films with glycerol in the presence of an emulsifier mechanically behave in the form of films with a larger amount of plasticizer. At 25% glycerol, an increase in tensile strength was observed that is likely to be due to the good dispersion and distribution of the added oil in the film caused by the addition of 5% lecithin. Itiswell known thatmechanical properties of emulsified films are improved when the hydrophobic compound is small and distributed more homogeneously (Debeaufort and Voilley, 1995). Resistance and elongation at break of starch films from four cassava vary between varieties. This difference in mechanical properties of films may be explained by the difference in amylose content of starches constituting these films. Indeed,as the amylose content of the starch increases at constant glycerol concentration, the tensile strength at break of the corresponding films increases while the elongation at break decreases (Alves*et al*., 2007).

IV. CONCLUSION

Starches of improved cassava varieties in Côte d'Ivoire can be used in the production of biodegradable films with plasticizer, lipid and emulsifier. Effect of plasticizer, lipid and emulsifier concentration on films from four improved cassava varieties was evaluated. The increased levels of glycerol, oil and soybean lecithin influenced the properties of cassava-based starch films. The resultant films from improved cassava starch with glycerol, peanut oil and soybean lecithin had satisfyingmechanical properties and low water solubility. However, to further optimize other biodegradable compounds must be added to formulation.

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Illustrations

Table.1: Cassava starch-based film formulations

Formulation	Starch (g)	Oil5 and 10% (g/g starch)	Glycerol 25 and 30% (g/g starch)	Lecithin0 and 5% (mg/g oil)	Potassiumsorbate (g)
F1: G25 H5 L0	4	0.2	1	0	0.2
F2: G25 H5 L5		0.2	1	30	
F3: G30 H5 L0		0.2	1.2	0	
F4: G30 H5 L5		0.2	1.2	30	
F5: G25 H10 L0		0.4	1	0	
F6: G25 H10 L5		0.4	1	60	
F7: FG30 H10 L0		0.4	1.2	0	
F8: G30 H10 L5		0.4	1.2	60	

G25 H5 L0 : 25 % glycerol/ 5 % oil/ 0% lecithin, G25 H5 L5 : 25 % glycerol/ 5 % oil/ 5% lecithin, G30 H5 L0 : 30 % glycerol/ 5 % oil/ 0% lecithin, G30 H5 L5 : 30 % glycerol/ 5 % oil/ 5% lecithin, G25 H10 L0 : 25 % glycerol/ 10% oil/ 0% lecithin, G25 H10 L5 : 25 % glycerol/ 10 % oil/ 5% lecithin, G30 H10 L0 : 30 % glycerol/ 10 % oil/ 0% lecithin, G30 H10 L5 : 30 % glycerol/ 10 % oil/ 5% lecithin.

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Table.2: Amylose content and pasteclarity of starches in cassavavarieties

Cassava starch	Bocou 1	Bocou 2	Yavo	TMS
Amylose content* (%)	16.28 ± 2.2^{a}	17.33 ± 1.2^{b}	18.37 ± 1.5^{c}	20.36 ± 2.1^{d}
Starch paste clarity* (% T)	71.02 ± 3.2^{a}	69.77 ± 2.5^{b}	61.33 ± 2.1^{c}	48.86 ± 1.3^{d}

*% T : percent transmittance, *the meansfollowed by a commonletter are not significantlydifferent by Duncan's multiple range test at p <0.05.*

Table.3: Water solubility of cassava starch-based composite films

Formulation	Solubility (%)			
	Bocou 1*	Bocou 2*	Yavo*	TMS*
G25 H5 L0	47.14 ± 1.48^{a}	42.88 ± 1.87^{a}	40.49 ± 2.75^{a}	37.15 ± 1.76^{a}
G25 H5 L5	49.13 ± 1.71^{ab}	43.90 ± 1.00^{ab}	41.61 ± 2.56^{ab}	39.61 ± 0.58^{ab}
G25 H10 L0	62.75 ± 3.36^{d}	61.67 ± 3.36^{d}	58.32 ± 2.43^{d}	52.99 ± 2.43^{d}
G25 H10 L5	66.34 ± 1.33^{e}	64.68 ± 0.81^{e}	60.50 ± 1.42^{e}	56.16 ± 1.24^{e}
G30 H5 L0	51.85 ± 1.24^{b}	45.95 ± 1.82^{b}	45.01 ± 2.18^{b}	44.35 ± 2.14^{b}
G30 H5 L5	53.82 ± 1.30^{c}	47.89 ± 1.07^{c}	48.65 ± 1.93^{c}	47.65 ± 2.02^{c}
G30 H10 L0	73.19 ± 2.84^{f}	69.53 ± 0.74^{f}	62.32 ± 0.56^{f}	59.65 ± 0.82^{f}
G30 H10 L5	74.63 ± 2.76^{g}	72.96 ± 1.23^{g}	64.50 ± 1.42^{g}	63.07 ± 0.78^{g}

**The meansfollowed by a commonletter are not significantlydifferent by Duncan's multiple range test at p <0.05.*

Table.4: Opacity of cassava starch-based composite films

Formulation	Opacity (AU nm^{-1})			
	Bocou 1*	Bocou 2*	Yavo*	TMS*
G25 H5 L0	110.64 ± 6.98^{a}	166.70 ± 15.05^{a}	169.21 ± 8.36^{a}	191.42 ± 4.61^{a}
G25 H5 L5	172.82 ± 6.40^{c}	257.27 ± 10.35^{c}	223.92 ± 3.41^{c}	251.42 ± 8.50^{c}
G25 H10 L0	155.65 ± 6.86^{b}	169.36 ± 3.47^{b}	208.15 ± 11.85^{b}	221.39 ± 3.30^{b}
G25 H10 L5	272.55 ± 11.19^{d}	322.62 ± 8.86^{d}	332.50 ± 12.09^{d}	348.66 ± 2.49^{d}
G30 H5 L0	132.82 ± 6.39^{a}	162.67 ± 7.02^{a}	181.56 ± 3.14^{a}	196.58 ± 1.77^{a}
G30 H5 L5	200.56 ± 5.13^{c}	264.62 ± 11.39^{c}	237.33 ± 8.49^{c}	259.06 ± 3.11^{c}
G30 H10 L0	171.47 ± 14.05^{b}	156.27 ± 7.15^{b}	209.09 ± 16.28^{b}	217.65 ± 6.71^{b}
G30 H10 L5	291.98 ± 5.07^{d}	299.29 ± 1.00^{d}	337.12 ± 17.07^{d}	348.57 ± 7.63^{d}

**The means followed by a common letter are not significantly different by Duncan's multiple range test at p <0.05.*

Table.5: Tensile strength and elongation at break values of cassava-based composite films

Formulations	Tensile Strength at break (MPa)				Elongation at break (%)			
	Bocou 1*	Bocou 2*	Yavo*	TMS*	Bocou 1*	Bocou 2*	Yavo*	TMS*
G25 H5 L0	2.82 ± 0.3^{a}	5.11 ± 1.2^{a}	5.26 ± 1.1^{a}	5.99 ± 1.6^{a}	15.08 ± 2.3^{a}	8.64 ± 1.8^{a}	8.20 ± 5.1^{a}	7.39 ± 1.7^{a}
G25 H5 L5	3.94 ± 1.6^{b}	6.22 ± 1.1^{b}	6.40 ± 1.2^{b}	7.92 ± 0.9^{b}	27.54 ± 3.2^{b}	18.17 ± 2.4^{b}	16.34 ± 2.1^{b}	17.82 ± 3.3^{b}
G25 H10 L0	0.96 ±	1.39 ±	1.26 ±	2.11 ±	73.66 ± 5.7^{e}	59.82 ±	60.12 ± 2.8^{e}	44.36 ±

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	0.2^{e}	0.3^{e}	0.1^{e}	0.5^{e}		3.4^{e}		4.7^{e}
G25 H10 L5	1.28 ± 0.1^{e}	1.49 ± 0.1^{e}	1.65 ± 0.2^{e}	2.23 ± 0.4^{e}	88.42 ± 1.6^{e}	73.28 ± 4.3^{e}	75.44 ± 4.8^{e}	54.23 ± 3.7^{e}
G30 H5 L0	2.08 ± 0.3^{c}	3.54 ± 0.4^{c}	3.90 ± 0.4^{c}	3.94 ± 0.4^{c}	35.77 ± 5.3^{c}	27.97 ± 2.6^{c}	21.47 ± 2.2^{c}	29.23 ± 6.0^{c}
G30 H5 L5	1.78 ± 0.6^{d}	2.51 ± 0.6^{d}	2.80 ± 0.6^{d}	2.98 ± 0.7^{d}	47.69 ± 4.3^{d}	35.16 ± 3.4^{d}	30.27 ± 4.2^{d}	30.91 ± 4.5^{d}
G30 H10 L0	0.71 ± 0.1^{f}	1.07 ± 0.3^{f}	1.09 ± 0.2^{f}	1.13 ± 0.1^{f}	95.44 ± 1.1^{f}	91.18 ± 2.8^{f}	87.41 ± 3.7^{f}	65.09 ± 2.1^{f}
G30 H10 L5	0.45 ± 0.1^{g}	0.69 ± 0.1^{g}	0.72 ± 0.1^{g}	0.89 ± 0.1^{g}	99.21 ± 1.4^{g}	99.50 ± 0.7^{g}	94.49 ± 3.8^{g}	85.56 ± 1.9^{g}

**The meansfollowed by a commonletter are not significantlydifferent by Duncan's multiple range test at p <0.05.*

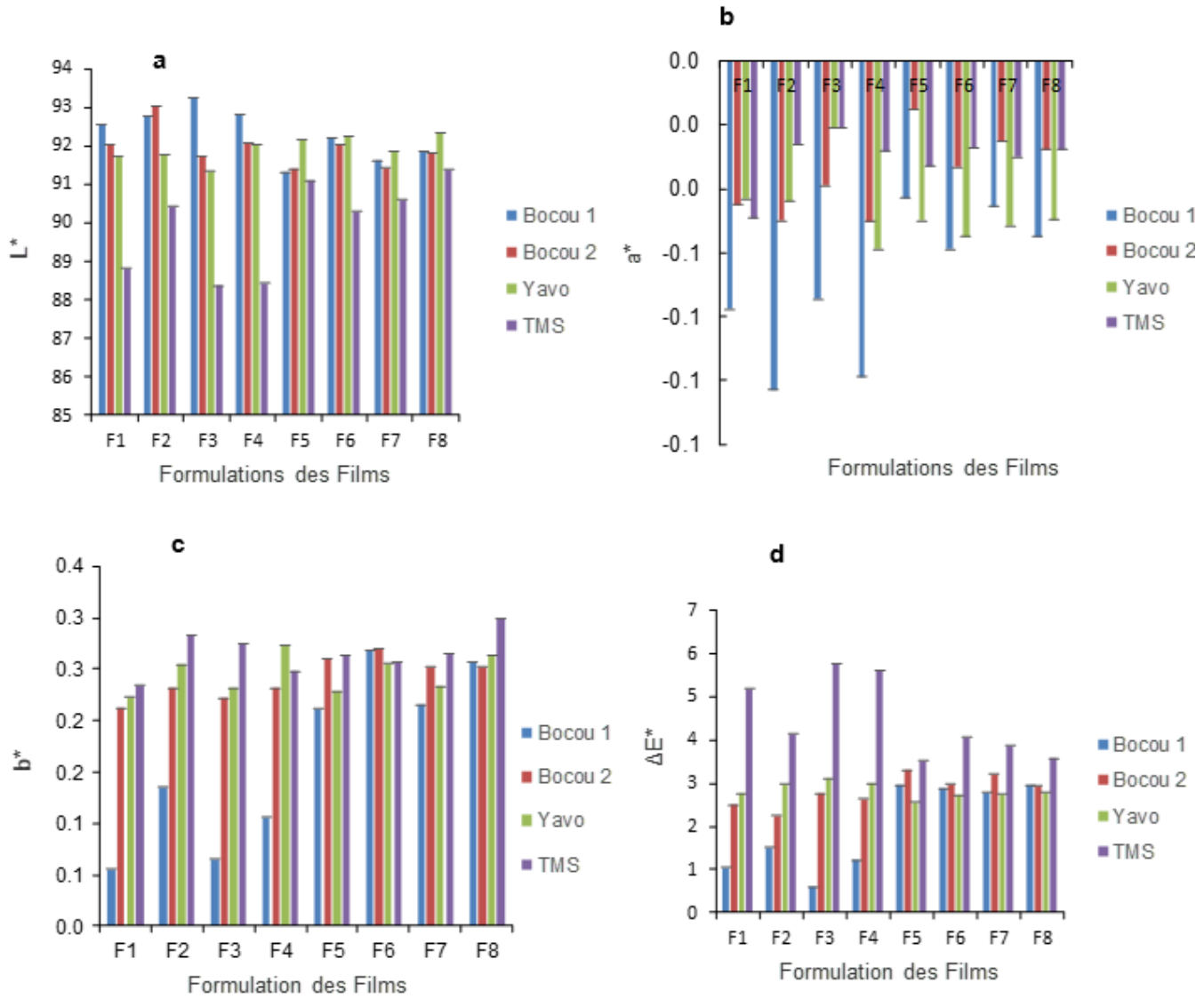

Fig.1: Effect of glycerol, oil and soy lecithin on the colour parameters of films based on cassava starch, a) color parameter L^*, b) color parameter a^*, c) color parameter b^*, d) ΔE^* indexes